DESIGN AND TESTING OF THE GIRDER SUPPORT SYSTEM FOR SSRF

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Abstract

As a third generation light source, the Shanghai Synchrotron Radiation Facility (SSRF) has a relatively large ground vibration than other similar light sources. Therefore, a very important issue is to improve the mechanical stability performance of the magnet girder assembly. In this paper, the design and fabrication of the girder are described. By using finite element analysis and vibration measurement, four different support types are investigated, and a new method is put forward to simulate the adjustment system with large amount of bolt connections. The dynamic performances of the MGA with and without auxiliary supports, including the first eigenfrequency, the Q value and the magnification are discussed in detail.

INTRODUCTION

The Shanghai Synchrotron Radiation Facility (SSRF) is a third generation light source under construction, which comprises a 3.5 GeV electron storage ring, injected from a 150 MeV linac through a full energy 0.15-3.5 GeV booster synchrotron, and an initial complement of 7 beam lines [1]. The storage ring is 432 m in circumference and consists of 20 similar cells. The support system for each cell including two supports for dipoles and three supports for quadeupoles and other components.

For the SSRF, the mechanical stability of the support system deserves more attention because the ground vibration at the site is much larger than other light sources. Moreover, the mechanical vibrations can be amplified on the electron beam closed orbit by more than ten times by the quadrupoles [2]. Therefore, the dynamic performance of the MGA in the storage ring is a very important issue for the light source. In this paper, we first introduce the design and fabrication of the girder. Next, we make comparisons for four different support types and investigate two different ways for simulating the adjustment system. Finally, the measurement results of the mechanical stability of the MGA are given.

We use ANSYS workbench 10.0 for finite element (FE) analysis. In the vibration measurements, we use the DH5920 data acquisition system and the 941-B seismometers with sensitivity of 23V·s/m and frequency range of 1-100 Hz.

DESIGN AND FABRICATION OF GIRDER

There are three MGAs in each cell of the storage ring. The MGA in the middle is the largest and heaviest, which is 4100mm long and 2.8 ton weight with 6.0 ton magnets on it. It includes four quadrupoles (Q260-002, Q260-003, Q320-002, Q320-003), three sexupoles and two corrector magnets (see Fig. 1). The girder consists of two parts, one is the girder body, and the other is the adjustment system.

The girder body is a box structure welded from steel plates of 30~40mm thick. In order to assure the long-time mechanical stability, heat treatment and vibration processing were performed after welding in order to eliminate the residual stress and keep its strength. The girder body has been optimized by FE.

In order to compare the static and dynamic performances under different adjustment systems, four different support types are analyzed by FE (see Fig. 2). Type A, B and C are three-point supports with different distribution and Type D is a four-point support with symmetric distribution.

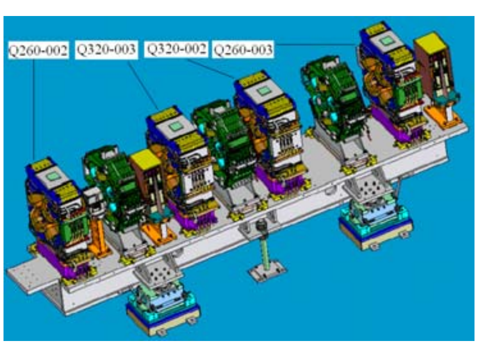


Figure 1: MGA in the middle cell.

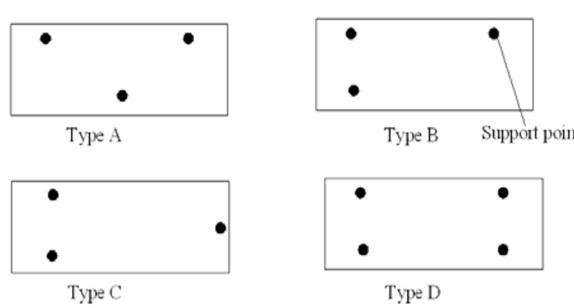


Figure 2: Four different support types.

Table 1: FE results of different support types

Support manner	The first eigenfrequency (Hz)	Maximum deformation (mm)
Type A	15.9	0.110
Type B	13.6	0.383
Type C	16.8	0.202
Type D	20.6	0.042

Tab. 1 shows the FE results. Here, the first eigenfrequency is mainly considered because it has lager influence than other by the fact that the displacement PSD of the ground decreases 4 times vs. frequency [3]. We can see that the static and dynamic performances of the four-point support system are better than other three-point supports. However, once any support point of Type D is set free because of uneven settlement of the ground, Type D turns into Type B, which has the worst performance among the four types. After synthetic consideration, we finally choose Type A. Fig. 3 shows the typical plots of Type A and D, where the maximum deformation of Type A is at the end of the long side with only one support point, and that of Type D is in the middle position of the MGA. Their modal shapes at the first eigenfrequencies are lateral rock and axial translation, respectively.

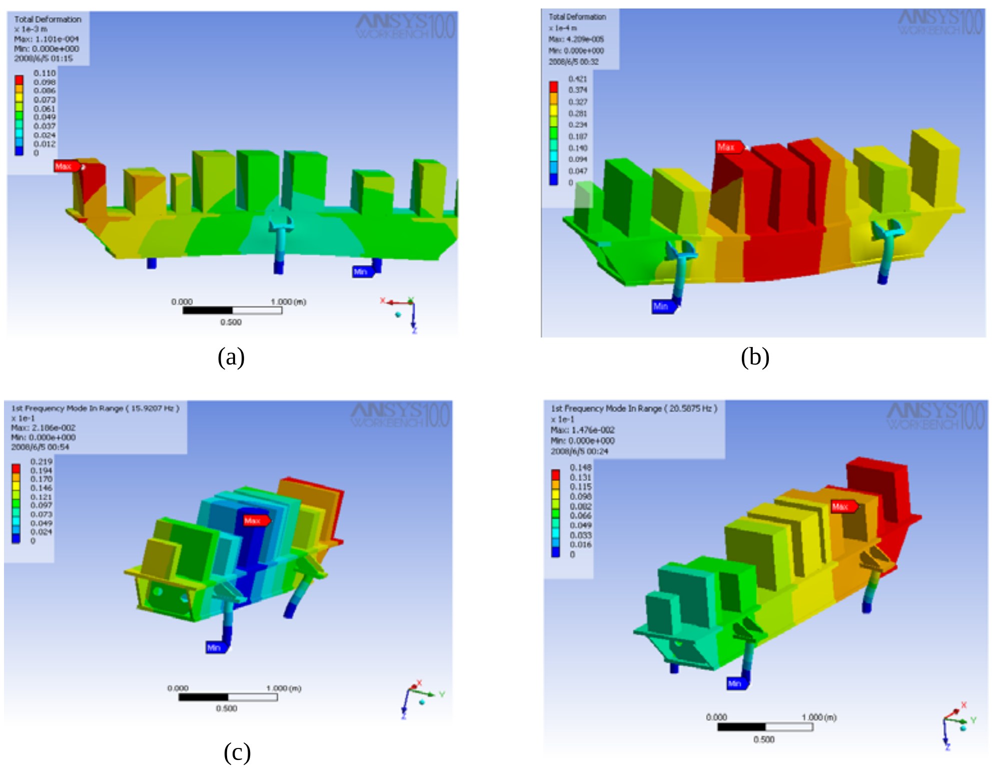


Figure 3: FE results of different support types: (a) and (b) static deformations of Type A and D, (c) and (d) modal shapes at first eigenfrequencies of Type Aand D.

FE ANALYSIS OF THE ADJUSTMENT SYSTEM

The adjustment system of the MGA is shown in Fig. 4, which adopts wedge jacks including a bearing system and a wedge system Wedge jacks are connected to the girder body by flanges. The slope angle of the wedge system is 7^{o} and the adjustment range is ±7mm in the vertical direction and ±10mm in the horizontal. The adjustment sensitivity can arrive 0.01mm. Horizontal directions are adjusted by screw rods. Anti-friction plates are used for convenient adjustment. In the bearing system, the diameter of the spherical bearing is 100mm. The spherical bearing in the wedge jack mechanism can rotate around the bearing bush only when the external moment exceeds 16 Nm, which can assure their good contact under the heavy load of the MGA.

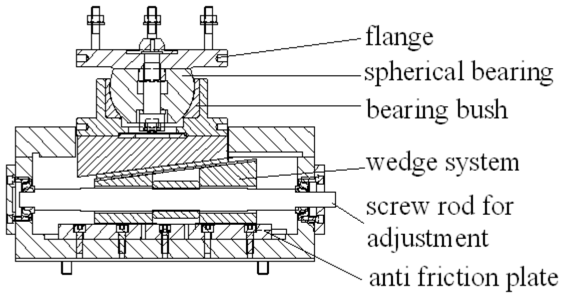


Figure 4: The adjustment system of the middle MGA.

There are large amount of bolt connections in the adjustment system, the components in these connections have different contact areas one another since each bolt has different preload, so it is difficult to simulate the adjustment system by FE. Fig. 5 shows the typical bolt connection, where the plates B1 and B2 are connected by a bolt. Tab. 2 presents two FE models. One is Model A, the usual model to solve the problem, where the bolt and the washer are omitted for simplification of calculation and bond contact is used between B1 and B2 with the area A1. Another is Model B, where the four contact types are defined including bond contact with the area A3 between bolt and washer, bond contact with the area A2 between washer and B1, bolt contact with area A4 between bolt and B2, no separate contact with the area A1 for static analysis, and no contact for dynamic analysis between B1 and B2.

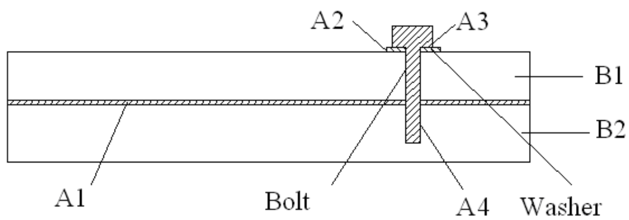


Figure 5: Schematic diagram of the bolt connection (A -- contact area, B – plate)

Table 2: FE model for simulating the bolt connection

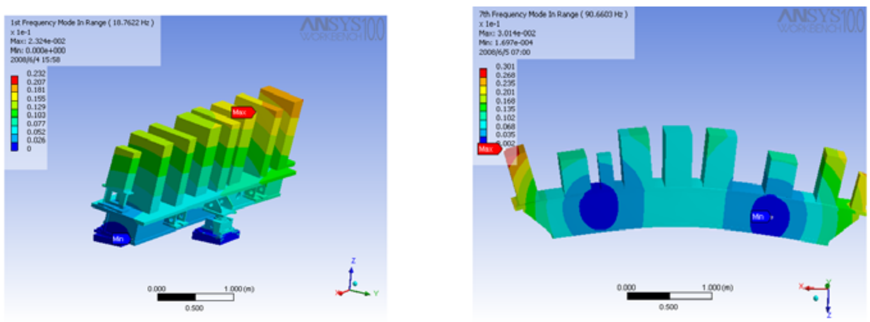
Model A			Model B		
Component	Contact type	Contact area	Component	Contact type	Contact area
B1, B2	Bond	A1	B1, B2	No separation (for static analysis)	A1
				No contact (for dynamic analysis)	
Bolt, washer are omitted for simplification			Bolt，washer	Bond	A3
			Washer, B1	Bond	A2
			Bolt, B2	Bond	A4

Tab. 3 shows the FE and measurement results of the whole MGA in two models. We can see that the value of Model A is far above the measurement's result with maximum relative error of 69%, which can be explained that in Model A, the contact type overestimates the bond area and the contact stiffness is higher than reality. On the other hand, the maximum relative error between the FE results in Model B and the measurement's is no more than 14%. Although the underestimation of the bond area, Model B is more precise than Model A and has better instruction for the mechanical design. Based on these discussions, we also can conclude that the stiffness of the MGA can be increased effectively by improving the fabrication precision of the components so as to add their bond contact areas.

Fig. 6a shows the modal shape of the MGA of Model B with lateral rock at the first eigenfrequency, and the case without the adjustment system is shown in Fig. 6b. We can see that the MGA has the first eigenfrequency of 91Hz with bend along the lateral direction, which suggests that the girder body has enough stiffness. Besides, comparison of these two figures shows that stiffness of the adjustment system has crucial effect on the dynamic performance of the whole MGA.

Table 3: Results of FE and vibration measurement

	Measurement	Model A		Model B	
		FE	relative error	FE	relative error
Lateral first eigenfrequency	21.9	34.9	60%	18.8	14%
Vertical first eigenfrequency	22.5	38.1	69%	22.4	1%



(a) (b)

Figure 6: Modal shape of the MGA of Model B with (a) and without (b) the adjustment system.

DYNAMIC PERFORMANCE OF THE MGA

Excited measurement has been performed to find out the first eigenfrequency of the MGA in the vertical and lateral directions. In the measurement, four seismometers are used. Two of them are put on the upper surface of Q260-002, Q320-003, and the other two on the girder. The excited point and the seismometer are kept unmovable throughout the measurement. The force and velocity signals are collected simultaneously when the girder is excited by hammer. Fig. 7 shows the spectra of frequency response function in the two directions，where only the Q260-003's velocity and force are displayed for clarify. We can see that the lateral and vertical first eigenfrequency are 21.9 and 22.5, respectively. Moreover, the lateral response at the first eigenfrequency is larger than the vertical, which implies that the vertical stiffness is higher than the lateral. We also notice that two peak appear at near 1 Hz. They are caused by the noise because no such phenomenon happens in the following transmissibility curves shown in Fig. 8.

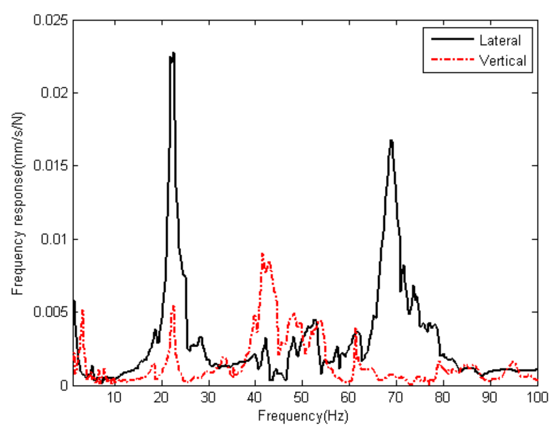


Figure 7: Spectra of frequency response function

In addition, response measurement has been conducted to compare the vibration between different quadrupoles and the floor. During the measurement, five sets of seismometers are put on the top surface of the four quadrupoles and the floor, respectively. Each set consists of two seismometers, one for the lateral direction, the other for the vertical. Data are derived simultaneously from the five places. Tab. 4 gives the Q260-003's results, the other quadrupoles' results are similar and not shown. The displacement in the table is the RMS displacement in 4-50Hz. We can find that the lateral and vertical displacement magnifications of Q260-003-to-floor are 1.34 and 1.05, respectively. The vertical vibration is much smaller than lateral. Fig. 8 shows the spectra of lateral transmissibility, from which we can see that the first eigenfrequency of 21.9 Hz is consistent with that in the above excited measurement, and the Q value (the peak value in the transmissibility curve at the first eigenfrequency) is 47.3.

Table 4: Vibration displacement in 4-50Hz (nm)

	Floor	Q260-003	Ratio
Vertical	39.0	41.1	1.05
Lateral	18.8	25.1	1.34
Lateral with auxiliary support	17.0	21.1	1.24

In order to improve the lateral dynamic performance of the MGA further, we adopt three auxiliary supports (shown in Fig. 9) to improve the lateral stiffness. Fig. 8 and Tab. 4 also display the corresponding lateral results, from which we can see that the lateral first eigenfrequency is improved from 21.9 Hz to 27.7 Hz, and the lateral displacement magnification of Q260-003-to-floor is decreased from 1.34 to 1.24 in 4-50 Hz. The mechanical stability performance is improved obviously.

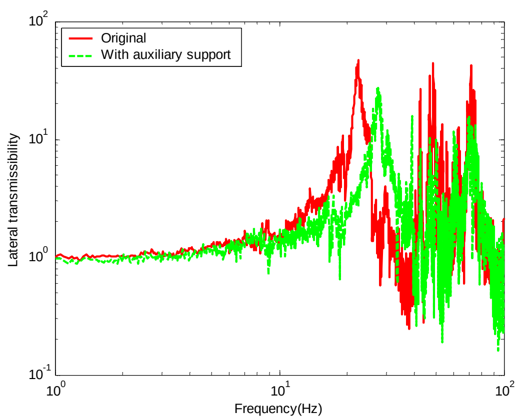


Figure 8: Lateral transmissibility between Q320-002 and floor

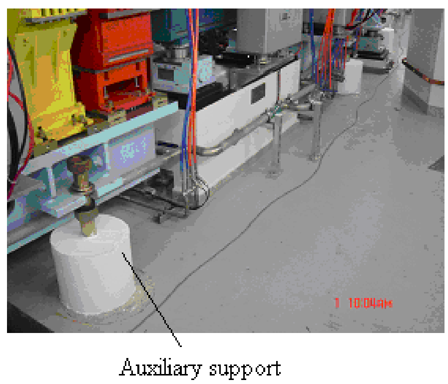


Figure 9: MGA with auxiliary supports

CONCLUSIONS

The mechanical stability performance of the MGA is very important for SSRF because it has a relatively larger ground vibration than other similar light sources. The following conclusions can be drawn from the present analysis:

1. The first eigenfrequency are 21.9 Hz and 22.5 Hz in the lateral and vertical directions, respectively. The lateral Q value is 47.3; and the lateral displacement magnification of the quadrupole-to-floor is 1.34 in 4-50 Hz.

2. By adding auxiliary supports, the lateral first eigenfrequency is improved to 27.7 Hz, and the lateral displacement magnification of the quadrupole-to-floor can be decreased to 1.24 in 4-50 Hz. The mechanical stability performance is improved obviously.

3. After detail comparison in the four different support types, SSRF adopts the three point support (Type A) for MGA.

4. For the adjustment system of the MGA with large amount of bolt connections, the FE model defined by four types of contacts is more precise than the usual simplified model.

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